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	Title **EMBEDDED SENSOR, METHOD FOR PRODUCING, AND TEMPERATURE/STRAIN FIBER OPTIC SENSING SYSTEM**	

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S00-042

PATENT APPLICATION

EMBEDDED SENSOR, METHOD FOR PRODUCING, AND REMOTE TEMPERATURE/STRAIN FIBER OPTIC SENSING SYSTEM

INVENTORS

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CROSS-REFERENCE TO RELATED APPLICATIONS

This application is based on Provisional application 60/142,348 filed 6/30/99 and Provisional application 60/187,240 filed 3/3/00, which are herein incorporated by reference.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

This invention was supported in part by grant numbers 2DJ12 554 and N00014-96-0354-P00002 from the Office of Naval Research (ONR). The Government has certain rights in the invention.

FIELD OF THE INVENTION

This invention relates generally to embedded sensors. More particularly, it relates to sensors embedded in high melting temperature metals, a method for embedding the sensors, and a system incorporating the sensors.

BACKGROUND ART

The need to obtain information on the performance and remaining lifetime of a tool is of prime importance to many

industries. Examples of applications include the manufacturing industry (molds, dies, drilling bits, etc.), the aerospace industry (components of jet engines), the oil industry (drilling equipment), the power industry (vessels and pipes). Such applications call for on-line acquisition of information such as temperature and strain values from tooling and structures. Temperature and strain information can only be obtained by placing sensors into those tools, and information from extended area can only be obtained from arrays of such sensors. Such a solution calls for the placement of the sensors near the points of interest, and therefore the issues of assembly and protection need to be addressed. The assembly of a large number of sensors is cumbersome, time-consuming, and costly, and this endeavor might become difficult for tooling operating in harsh environments. Since the sensors are embedded into functional metallic structure, non-obtrusive embeddability is very important to maintain the integrity of the functional metallic structures. The sensors ought to be small in size and rugged inside the metal matrix. Thin film thermo-mechanical sensors and fiber optic sensors have been identified as two promising candidates.

Fiber optic sensors offer a series of advantages over conventional electronic sensors used to measure temperature, strain, ultrasonic pressure, and other properties. These advantages include small size, high sensitivity, immunity to electromagnetic interference, high temperature capability, multiplexing potential, and low cost.

The small size makes fiber optic sensors good candidates for embedding within structures. Embedded sensors measure parameters at locations not accessible to ordinary sensors, and allow for real-time measurements during fabrication and use of structures. They can also be used for non-contact

measurements because they do not require wiring between the sensor and detector. In addition, embedded sensors are protected from damage and isolated from environmental effects to which the structure is subject. While embedding sensors in composite materials is a common process, no successful techniques have been developed for embedding sensors in metal structures with high melting temperatures. During metal casting, in which an enormous temperature change is suddenly applied to the sensor, the sensor undergoes extreme thermal stress and cracks. Silica-based fibers cannot withstand the processing of metals with melting temperatures above 1100 °C.

Surviving processing is only one requirement of embedded sensors. Fiber sensors measure strain by measuring fiber displacement, which manifests in a change of a measured property of the light travelling through the fiber. The embedded fiber must, therefore, expand or contract with the metal during measurement, without slipping. There must also be good bonding between the fiber and metal. Without adequate bonding, the fiber slips at the interface during temperature- or stress-induced displacement, resulting in poor measurements.

A method for embedding fiber optic sensors in aluminum, which has a melting temperature of 660 °C, has been disclosed by Lee et al., entitled "Method for Embedding Optical Fibers and Optical Fiber Sensors in Metal Parts and Structures" issued in Fiber Optics Smart Structures and Skins IV, SPIE, Vol. 1588, pp. 110-116 (1991). The fiber sensor is positioned in a graphite mold, machined with desired shape, having one optical fiber tube held at one side and a stainless steel held at the opposite side. One end of the fiber sensor is passing through the stainless steel tube and the another end passing through the optical fiber tube. It is believed that the tubes reduce

the stress discontinuity at the air-metal interface, allowing the fibers to withstand aluminum casting. Then molten aluminum is poured into the mold. However, Lee's method only works for metals having low melting temperatures. Embedding a fiber optic sensor in a metal structure having high melting temperature will decay the fiber, thus damage the sensor.

Another article entitled "Sensing Applications of Fiber Fabry Perot Interferometers Embedded in Composites and in Metals" by Taylor and Lee, issued in Experiments in Smart Materials and Structures, ASME, AMD-Vol. 181, pp. 47-52 (1993) has disclosed a Fiber Fabry Perot Interferometer (FFBI) as a strong candidate for embedding in a composite or metal part to measure properties of this structure using the method described in the above prior art, "Method for Embedding Optical Fibers and Optical Fiber Sensors in Metal Parts and Structures". However, the composite layer doesn't bond with nonmetal coating layers of the FFBI, thus the FFBI slips during the measurement.

Furthermore, for metals with higher melting temperatures, for example, stainless steel, nickel, iron, or titanium, all of which have melting temperatures above 1400 °C, no solution has been disclosed.

There is a need, therefore, for an embedded fiber optic sensor and a method for embedding a fiber optic sensor in a high melting temperature metal structure, in which the resulting embedded sensor adheres strongly to the metal in which it is embedded.

OBJECTS AND ADVANTAGES

Accordingly, it is a primary object of the invention to provide embedded fiber optic and thin film thermo-mechanical

sensors for measuring temperature, strain, or other properties in high melting temperature metal structures. The embedded sensors have greater accuracy and sensitivity than conventional strain gauges and thermocouples.

It is a further object of the present invention to provide a method for embedding fiber optic and thin film thermo-mechanical sensors in high melting temperature metal structures. The present method combines low temperature coating processes with high temperature embedding processes to create an overall process that does not damage the sensor.

It is an additional object of the invention to provide a remote fiber optic sensing system for measuring temperature and strain in a high melting temperature metal. An advantage of this system over standard measurement systems is that it can be used in hostile environments, in which the sensing area is difficult to reach, and in cases in which electrical signal transmission from the sensing area is not feasible.

It is another object of the present invention to provide a remote fiber optic sensing system for measuring temperature and strain in a rotating metal structure. The system is a non-contact measurement system, in which measurement information is transferred from the structure to a detector through an aligned light beam, which enters the structure at its rotational axis.

SUMMARY

These objects and advantages are attained by an embedded fiber optic or thin film thermo-mechanical sensor, a method for producing the embedded sensor, and an embedded fiber optic sensing system. A fiber optic sensor or a thin film thermo-mechanical sensor is embedded in a metal having a melting

temperature above 660°C, and the metal is uniformly and closely bonded with the outer surface of the sensor. The embedded sensor can be used to measure temperature and strain in the metal.

A first embodiment of the present invention describes a method for embedding a sensor in a metal structure having a melting temperature above 660°C. A first thin metallic layer is sputter-deposited onto the sensor. This first thin metallic layer forms a conducting surface for the deposition of the next layer. A second thin metallic layer is electroplated onto the first metallic layer, and a metal structure, for which measurements is obtained by the sensor, is laser deposited on the second thin metallic layer.

The method described in the first embodiment is applied for producing an embedded fiber optic sensor according to a second embodiment of the present invention. An embedded fiber optic sensor includes a fiber optic sensor and a metal structure. The metal structure includes a coating layer around the sensor and a bulk metal, for which measurements are obtained, around the coating layer. Most preferably, the coating layer includes a first thin metallic layer and a second thin metallic layer around the first thin metallic layer. The first metallic layer is formed by magnetron sputtering and typically has a thickness of between about 1μm and about 3 μm. The second metallic layer is formed by electroplating on the first metallic layer and typically has a thickness of between about 0.25mm and about 2mm. Both layers can be composed of any suitable metal, for example, nickel, iron, or platinum, and do not need to be of the same metal. The bulk metal is formed around the second metallic layer with a high-temperature process, which is preferably a laser deposition such as laser

cladding, casting and welding, whereby the sensor is embedded in the metal structure.

The method described in the first embodiment is also applied for producing an embedded thin film thermo-mechanical sensor according to a third embodiment of the present invention. The embedded thin film thermo-mechanical sensor has similar structure with the embedded fiber optic sensor as described in the above second embodiment, which includes a thin film thermo-mechanical sensor and a metal structure. Thin film thermo-mechanical sensors consist of two insulating layers sandwiching a sensor layer. The metal structure includes a coating layer coating the sensor and a bulk metal, for which measurements are obtained, around the coating layer. The coating layer includes a first thin metallic layer covering the thin film sensor and a second metallic layer on the first metallic layer. The first thin metallic layer is formed by sputtering, and the second metallic layer is formed by the electroplating. Thin film thermo-mechanical sensors are sputter-deposited and shaped via photolithography. An adhesive layer of Ti is sputter-deposited on a substrate of stainless steel. A first insulating is sputtered on the adhesive layer, which provides the sensors with adequate electrical insulation from the stainless steel substrate. Sensor films are sputter-deposited on the first insulating layer, and shaped with micromachining combining photolithography and a lift-off. A second insulating layer is sputtered on the sensor films. The coating layer protects the thin film structure from the high-temperature embedding process. A first thin metallic layer is formed by sputtering on the top dielectric film serving as a seed for the electroplating of a second thicker metallic layer. The whole structure is embedded in the bulk metal with a high-temperature process, which preferably is laser deposition such as laser cladding, casting and welding.

The first metallic layer is preferably made of copper since copper is a good candidate for minimizing temperature gradients so that the thin film sensor layer will undergo less localized thermal stress. The second metallic layer formed by electroplating includes two metallic sublayers. The first sublayer contacting the first metallic layer is made of copper about 1mm thick to make the temperatures more inform in the sensor layer and protect the thin film sensor. However, copper will not form good bonding with later laser deposited bulk metal. To facilitate the in embedding process, a second sublayer is made of nickel with a thickness of between about 1mm and about 2mm to form a good bonding with laser deposited layer.

The embedded fiber optic sensor described in the second embodiment may be incorporated in a remote embedded fiber optic sensing system to measure properties, such as temperature and strain, in a metal structure having a melting temperature above 660°C according to a fourth embodiment of the present invention. The system contains a first fiber optic sensor embedded in the metal structure, a first and a second embedded optical fiber leads, with a first end connected to the fiber optic sensor and a second end at an external surface of the metal structure, and an optical system. The optical system has a light source for generating a light beam and a first light aligning means for directing the light beam into the second end of the first embedded optical fiber lead. An output signal from the sensor exits the second embedded optical fiber lead and is directed by a second light aligning means to a photo-detector. A PC data acquisition system collects the output voltage from the light source and the photo-detector for processing the output signals to obtain temperature, strain, or other information.

In an alternate embodiment, a fiber embedded in the metal structure may include multiplicity of sensors having different wavelengths, therefore different output signals are obtained. All of the sensors are connected to the same embedded optical fiber lead to form a multiplexed sensing system. Any number of sensors can be multiplexed. In another alternative embodiment, one or more fibers can be embedded in a metal structure at different sites, therefore properties at different locations of the metal structure are measured.

BRIEF DESCRIPTION OF THE FIGURES

Fig. **1** is a schematic diagram of a sputtering system used by the method according to the first embodiment of the present invention;

Fig. **2** is a schematic of an electroplating system used by the method of the present invention;

Fig. **3** is a perspective view of the embedded fiber optic sensor according to a second embodiment of the present invention;

Fig. **4A** is a cross-sectional schematic diagram of the embedded thin film thermo-mechanical sensor according to a third embodiment of the present invention;

Fig. **4B** is a perspective view of the embedded thin film thermo-mechanical sensor depicted in Fig. 4A;

Fig. **5** is a schematic diagram of a remote non-contact sensing system according to a fourth embodiment of the present invention; and

Fig. **6** is a graph depicting the waveform of the voltages from the light source and the photo-detector for the sensing system depicted in Fig. 5 with a Fiber Bragg Grating sensor embedded in a metallic structure.

DETAILED DESCRIPTION

Although the following detailed description contains many specifics for the purposes of illustration, anyone of ordinary skill in the art will appreciate that many variations and alterations to the following details are within the scope of the invention. Accordingly, the following preferred embodiment of the invention is set forth without any loss of generality to, and without imposing limitations upon, the claimed invention.

The present invention provides an embedded sensor for measuring properties, for example, temperature and strain, of a high melting temperature structure. The embedded sensor is closely and uniformly bonded to the surrounding metal structure for maximum accuracy. Any suitable sensor type can be used, for example, a thin film thermo-mechanical sensor or a fiber optic sensor such as a fiber grating sensor or Fabry-Perot sensor.

A method for embedding a sensor in a metal structure having a melting temperature above 660 °C is also provided to measure the temperature and/or strain of this metal structure according to a first embodiment of the present invention. Using a combination of low temperature coating processes and high temperature embedding processes, the sensor is embedded in the metal without being damaged or suffering a reduction in performance. The low temperature processes include the steps of magnetron sputtering of a first thin metallic layer on the sensor, and electroplating a second thin metallic layer on the first thin metallic layer. The high temperature processes include the step of laser deposition to form a metal structure having properties measured by the sensor.

Fig. 1 is a schematic diagram illustrating a first step of the low temperature processes. Sensor **102** is supported on a sputtering support **106.** A sputtering tool **104** produces metal atoms **108** that coat sensor **102**. Sputtering support **106** can include a metal substrate, which becomes part of the metal structure formed in a subsequent step. Sensor **102** is placed inside a V-groove in the substrate. Metal atoms **108** form a first thin metallic layer on sensor **102.** The thin metallic layer adheres well to sensor **102,** and there are no significant gaps between the first thin metallic layer and sensor **102.** The thickness of the first metallic layer is preferably between about $1\mu m$ and $3\mu m$. Metal atoms **108** can be copper, nickel, iron, platinum, or any other metal that adheres to sensor **102** and is suitable for the following step. The first thin metallic layer provides a conducting surface for electroplating the second thin metallic layer as shown in Fig. 2. The first thin metallic layer may alternatively be produced by any standard thin film forming technique, including Physical Vapor Deposition or Chemical Vapor Deposition techniques.

A second step of the low temperature processes is shown schematically in Fig. 2. A second thin metallic layer, preferably between about 0.25mm and about 2mm thick, is electroplated onto the first thin metallic layer. An electrode **204** and a sensor with first thin metallic layer **202** are immersed in a metal electrolyte solution **206.** A voltage source **208** is connected between the sensor with first thin metallic layer **202,** the cathode, and electrode **204,** the anode. The voltage between the sensor **202** and the electrode **204** directs the ions toward the sensor **202**. Metal electrolyte solution **208** contains ions of copper, nickel, iron, platinum, or any other metal that make a good bonding with later embedding metallic layer. Thus a second thin metallic layer is plated onto the

sensor **202**. The two thin metallic layers can be formed from the same or different metals.

In essence, the two metallic layers form a single layer having a thickness of between about 0.25mm and about 2mm. The two steps provide a convenient method for forming such a layer. Sputtering alone is not a feasible technique for producing a layer of such thickness, and electroplating requires a conducting surface, in this case provided by the sputtered layer.

In the third step of the process, an embedding metallic layer or a metal structure is formed on the second thin metallic layer, whereby the sensor is embedded in this metal structure. The embedded sensor measures properties of this metal structure, such as temperature or strain. The metal structure may be made of a metal having a melting temperature well above 660°C, for example, stainless steel, nickel, iron, or titanium, which all have melting temperatures above 1400°C. The technique for forming the metal structure is the same as is used to form the structure without an embedded sensor. These techniques include, but are not limited to, laser cladding, casting, and welding.

The first and second metallic layers, formed by low temperature processes, protect the sensor from the subsequent high-temperature process for forming the metal structure. If the metal structure were formed directly around the sensor, the thermal shock would cause the sensor to crack. The first and second thin metallic layers reach the same temperature as the metal structure upon contact with the molten metal, but the balanced heat load allows the sensor to expand uniformly without cracking in response to the dramatic thermal stresses.

The method described above is used for embedding a fiber optic sensor in a metal structure. Fig. 3 illustrates a perspective view of an embedded fiber optic sensor **300** according to a second embodiment of the present invention. The embedded fiber optic sensor **300** includes a fiber optic sensor element **302**, a first thin metallic layer **304** formed by a sputtering step, a second thin metallic layer **306** formed by an electroplating step, and a metal structure **308** formed by a laser depositing step. Furthermore, the fiber optic sensor **302** is coated by an adhesive layer of Titanium about 1 micron thick before the sputtering of the first metallic layer **304**. Typically, the diameter of sensor **302** surrounded by first thin metallic layer **304** and second thin metallic layer **306** is between about 0.3mm and about 2mm, and so does not affect the structure or temperature profile of metal structure **308**, for which measurements are required. Fiber optic sensor element **302** may be fiber Bragg gratings or Fabry-Perot fiber sensors.

The above method also can be used for embedding a thin film thermo-mechanical sensor. Fig. 4A shows a cross-sectional schematic diagram of an embedded thin film thermo-mechanical sensor **400** according to a third embodiment of the present invention. The embedded thin film sensor **400** is formed by sputter-depositing an adhesive layer of titanium between about 1mm and about 2mm thick **402** on a substrate of stainless steel 3mm thick **401**. A first insulating layer of between about 10nm and about 15nm thick **404** is reactively sputtered on the adhesive layer **402**. The insulating layer **404** provides the sensor with adequate electrical insulation from the substrate **401**. Sensor film **406** is sputtered-deposited and shaped via photolithography on the insulating layer **404**. The materials used for the sensor film **406** are selected with respect to their thermo-electric properties. The standard thermocouple alloys and metals, such as alumel, chromel, constanan and

copper, may be used to build the sensor film **406**. A second insulating layer of between about 10nm and about 15nm **408** is sputtered on the sensor layer **406** to partly cover the sensor. The first and second insulating layers are preferably made of the same material. Aluminum oxide is chosen as the preferred material for the insulating layers **404** and **408** based on its thermal expansion coefficient compatibility and target cost.

A first thin metallic layer **410** is sputtered on the insulating layer **408** and a second thin metallic layer **412** is electroplated on the first insulating layer **410.** The purpose of these layers **410** and **412** is to protect the thin film structure, including insulating layers **404** and **408** and the sensor layer **406**, from the high-temperature embedding process. These layers are necessary to reduce the temperature effect experienced by the thin films as an intense and localized heat flux imparted by the laser during the formation of the embedding layer. Copper is a preferred material for layer **410** that minimize temperature gradients so that the thin film sensor layer **406** will undergo less localized thermal stress. However, copper will not form good bonding with later laser deposited metal layer. Therefore, the second metallic layer **412** preferably includes two sublayers **414** and **416**. The sublayer **414** contacted to the first metallic layer **410** is preferably made of copper to make the temperature more uniform in the sensor layer **406**. The subslayer **416** is preferably made of nickel, which makes good bonding with later laser deposited layer, to success the embedding process.

The embedding metal layer **414** is deposited on the second insulating layer **410** by laser casting, cladding or welding. A perspective view of the embedded thin film thermo-mechanical sensor 400 is shown in Fig. 4B.

The embedded fiber optic sensor depicted in Fig. 3 is incorporated in a remote non-contact sensing system for measuring properties, such as temperature and strain, in structures, specially for a rotating metal structure, such as a turbine blade. Fig. 5 is a schematic view of the remote embedded fiber optic non-contact sensing system **500** according to a fourth embodiment of the present invention. The system of Fig. 5 measures properties, such as temperature and strain, in a rotating metal structure **504.** A sensor **300** is embedded in a rotating metal structure **504.** A light source **522** providing light beam couples to the sensor **300** through a first embedded optical fiber lead **506** with the first end of the lead **506** connected with the sensor **300** and the second end adjacent to an external surface **505** of structure **504** substantially parallel to the rotational axis **502** of structure **504.** Depending on the types of sensor **300**, light source **522** can be any low coherence, broadband spectral source, or tunable light source, for example, a wavelength tunable laser, a laser-emitting diode (LED) or multi-mode laser diode. A first aligning means **510**, such as an aligning lens, directs the light beam from the light source **522** to the first embedded optical lead **506**. An optical isolator **514** between the aligning means **510** and the light source **522** prevents the reflected light beam reflected from the sensor **300** from reaching the light source **522**, which prevents the damaging of the light source **522**.

A photo-detector **520** collecting output signals modulated by the material properties of the structure **504**, couples to the sensor **300** through the second embedded optical fiber lead **508** having a first end connected to the sensor **300** and a second end adjacent to an external surface **505** of structure **504** substantially parallel to the rotational axis **502** of structure

504. The second aligning means **512** directs the output signals from the sensor **300** to the photo-detector **520**.

The length of fiber leads **506** and **508** depend on the design of structure **504.** They must be long enough to reach from sensor **300** to the external surface **505** of structure **504.** Because the fiber leads **506** and **508** are positioned parallel to the rotational axis **505**, the relative position of the fiber **506** and **508** and the aligning means **510** and **512** respectively are fixed, even as the structure **504** rotates at very high speeds. Furthermore, Erbium-doped fibers **516** and **518** may be used to amplify the optical signals if light loss is a concern due to small size of optical fibers.

A data acquisition system **524** connected to the light source **522** and the photo-detector **520** collects the voltage output data from the photo-detector **520** and the voltage output form the light source **522**, which are measured after each rotation of the structure **504**. By knowing the voltage outputs as functions of time from the light source **522** and the photo-detector **520**, the wavelength versus time can be determined. The sensor **300** reflects material properties, such as temperature or strain, of the structure **504** in only one single wavelength, thus all other lights with different wavelength will go through to the photo-detector **520**. Thus, at that single wavelength, the received light intensity will drop to almost zero. In this way, a wavelength corresponding to the sensor **300** response of the material property can be determined. Therefore, the material properties of the structure **504** are determined.

Fig. 6 shows a typical waveform of the voltages from the light source and the photo-detector for the remote sensing system **500** with a fiber Bragg grating sensor embedded in the rotating

metal structure **504**. The laser wavelength is given in term of its output voltage, $\lambda(nm) = 27.616 \times V_{laser\ diode} + 1387.1$. The wavelength tuning range in the experiment is set between 1545nm and between 1555nm. At room temperature, about 22°C, the wavelength is found to be 1548.1nm (5.83 volts as $V_{laser\ diode}$), which is obviously shifted from 1550nm due to the residual stress after the laser deposition. When temperature rises to about 60°C, the wavelength shifts to 1549.3nm (5.873 volts as $V_{laser\ diode}$).

In an alternative embodiment, an optical fiber embedded in the metal structure may include multiple sensors having different wavelengths, therefore different output signals are obtained. All of the sensors are connected to the same embedded optical fiber lead to form a multiplexed sensing system. Any number of sensors can be multiplexed. In another alternative embodiment, one or more fibers can be embedded in a metal structure at different sites, and couple with the light source and the photo-detector through different embedded optical fiber leads, therefore properties at different locations of the metal structure are measured.

It will be clear to one skilled in the art that the above embodiment may be altered in many ways without departing from the scope of the invention. For example, the first thin metallic layer can be formed by other techniques such as evaporation. Accordingly, the scope of the invention should be determined by the following claims and their legal equivalents.

CLAIMS

What is claimed is:

1. A method for embedding a sensor in a metal structure comprising:
   a) sputtering a first metallic layer on the sensor;
   b) electroplating a second metallic layer on the first metallic layer; and
   c) forming an embedding metallic layer on the second metallic layer, whereby the sensor is embedded in the metal structure.

2. The method of claim 1, wherein the sensor is a fiber optic sensor.

3. The method of claim 2 further comprising coating the sensor with an adhesive layer.

4. The method of claim 1, wherein the sensor is in the form of a thin film thermo-mechanical sensor.

5. The method of claim 4, wherein the sensor is formed by:
   i) depositing an adhesive layer on a substrate;
   ii) depositing a first insulating layer on the adhesive layer;
   iii) sputter-depositing and shaping a sensor layer on the first insulating layer; and
   iv) depositing a second insulating layer on the sensor layer.

6. The method of claim 5, wherein the first metallic layer is sputtered on the second insulating layer of the sensor.

7. A metal embedded sensor comprising:
a metal structure comprising a metal having a melting temperature above 660°C; and
a sensor embedded inside the metal structure.

8. The metal embedded sensor of claim 7, wherein the metal structure comprises:
a coating metallic layer; and
an embedding metallic layer on the coating metallic layer.

9. The metal embedded sensor of claim 8, wherein the embedding metallic layer is formed by laser deposition.

10. The metal embedded sensor of claim 8, wherein the coating metallic layer comprises a first metallic layer, and a second metallic layer on the first metallic layer.

11. The metal embedded sensor of claim 10, wherein one or more of the first and the second metallic layers is formed by sputtering.

12. The metal embedded sensor of claim 10, wherein one or more of the first and the second metallic layers is formed by electroplating.

13. The metal embedded sensor of claim 10, wherein the first metallic layer is formed by sputtering, and the second metallic layer is formed by electroplating.

14. The metal embedded sensor of claim 10, wherein the thickness of the first metallic layer is between about one and about three microns.

15. The metal embedded sensor of claim 10, wherein the first metallic layer comprises a metal selected from the group consisting of copper, nickel, iron, and platinum.

16. The metal embedded sensor of claim 10, wherein the thickness of the second metallic layer is between about one-quarter and about two millimeters.

17. The metal embedded sensor of claim 10, wherein the second metallic layer comprises a metal selected from the group consisting of copper, nickel, iron, and platinum.

18. The metal embedded sensor of claim 17, wherein the sensor is in the form of a fiber optic sensor.

19. The metal embedded sensor of claim 18, further comprising an adhesive layer coating the sensor.

20. The metal embedded sensor of claim 19, wherein the adhesive layer comprises titanium.

21. The metal embedded sensor of claim 20, wherein the thickness of the adhesive layer is between about 2nm and about 3nm.

22. The metal embedded sensor of claim 17, wherein the sensor is in the form of a thin film thermo-mechanical sensor.

23. The metal embedded sensor of claim 22, wherein the sensor comprises:
a first insulating layer ;
a sensor layer disposed on the first insulating layer; and
a second insulating layer disposed on the sensor layer.

24. The metal embedded sensor of claim 23, wherein the sensor further comprises an adhesive layer contacting the first insulating layer.

25. The metal embedded sensor of claim 24, wherein the adhesive layer comprises titanium.

26. The metal embedded sensor of claim 25, wherein the thickness of the adhesive layer is between about 2nm and about 3nm.

27. The metal embedded sensor of claim 26, wherein the sensor further comprises a substrate contacting the adhesive layer.

28. The metal embedded sensor of claim 27, wherein the substrate comprises a metallic substrate.

29. The metal embedded sensor of claim 28, wherein the substrate comprises stainless steel.

30. The metal embedded sensor of claim 23, wherein the sensor layer comprises constantan.

31. The metal embedded sensor of claim 23, wherein the thickness of the first insulating layer is between about 10nm and about 15nm.

32. The metal embedded sensor of claim 23, wherein the thickness of the second insulating layer is between about 10nm and about 15nm.

33. The metal embedded sensor of claim 23, wherein the first and the second insulating layers comprise insulating oxides.

34. The metal embedded sensor of claim 33, wherein the first and the second insulating layers comprise alumina.

35. A remote non-contact sensing system to monitor the properties of structure having melting temperature above 660°C comprising:
a first metal embedded fiber optic sensor embedded in the structure;
a light source coupling to the first metal embedded fiber optic sensor; and
a photo-detector coupling to the first metal embedded fiber optic sensor.

36. The sensing system of claim 35, wherein the first metal embedded fiber optic sensor comprises:
a metal structure comprising a metal having a melting temperature above 660°c; and
a fiber optic sensor embedded inside the metal structure.

37. The sensing system of claim 36, wherein the metal structure comprises:
a coating metallic layer; and
an embedding metallic layer on the coating metallic layer.

38. The sensing system of claim 37, wherein the coating metallic layer comprises a first metallic layer, and a second metallic layer on the first metallic layer.

39. The sensing system of claim 38, wherein the first metallic layer is formed by sputtering.

40. The sensing system of claim 39, wherein the second metallic layer is formed by electroplating.

41. The sensing system of claim 40, wherein the embedding metallic layer is formed by laser deposition.

42. The sensing system of claim 40, wherein the embedding metallic layer is formed by casting.

43. The sensing system of claim 40, wherein the embedding metallic layer is formed by welding.

44. The sensing system of claim 35, wherein the light source comprises a wavelength tunable laser.

45. The sensing system of claim 44, wherein the tunable laser produces light having discrete wavelengths.

46. The sensing system of claim 35, wherein the light source comprises broad band laser diodes.

47. The sensing system of claim 46, wherein the broad band laser emits light with a broad spectra.

48. The sensing system of claim 35, wherein the light source couples to the sensor through a first optical fiber lead embedded inside the structure.

49. The sensing system of claim 48, wherein the first optical fiber lead comprises a first end connected to the first metal embedded fiber optic sensor and a second end adjacent to an external surface of the structure.

50. The sensing system of claim 49, further comprising a first aligning means for directing a light beam from the light source to the first end of the first optical fiber lead.

51. The sensing system of claim 50, wherein the first aligning means comprises an aligning lens.

52. The sensing system of claim 50, further comprising an isolator between the first aligning means and the light source to prevent the reflected light beam reflected from the first metal embedded fiber optic sensor.

53. The sensing system of claim 52, further comprising a first Erbium-doped fiber (EDF) between the light source and the isolator to amplify optical signals.

54. The sensing system of claim 35, wherein the photo-detector couples to the first metal embedded fiber optic sensor through a second optical fiber lead embedded inside the structure.

55. The sensing system of claim 54, wherein the second optical fiber lead comprises a first end connected to the first metal embedded fiber optic sensor and a second end adjacent to an external surface of the structure.

56. The sensing system of claim 55, further comprising a second aligning means for directing an output signal, modulated by a material property of the structure, from the first metal embedded fiber optic sensor to the photo-detector.

57. The sensing of claim 56, wherein the second aligning means comprises an aligning lens.

58. The sensing system of claim 57, further comprising a second EDF between the second aligning means and the photo-detector to amplify the optical signals.

59. The sensing system of claim 35, further comprising a data acquisition system connected to the photo-detector and the light source.

60. The sensing system of claim 35, further comprising a second metal embedded fiber optic sensor embedded in a different location in the structure.

61. The sensing system of claim 35, wherein embedded fiber optic sensor comprises one or more sensors.

62. The sensing system of claim 35, wherein the structure is a rotating structure having a rotational axis.

63. The sensing system of claim 62, wherein the first and second optical fiber leads are positioned substantially parallel with the rotational axis of the rotating structure.

S00-042

ABSTRACT OF THE DISCLOSURE

A method for embedding fiber optic sensors in a high melting temperature metal structure produces embedded sensors that are uniformly and closely bonded with the metal and do not slip upon metal expansion and contraction. The structure is built in layers. A first thin metallic layer, approximately 1-3 μm thick, is sputter-coated onto the sensor. Next, a second thin layer, approximately 0.25-2 mm thick, is electroplated onto the first thin metallic layer. Finally, a metal structure is built around the thin metallic layers by laser cladding, casting, welding, or other method. The embedded sensor is incorporated into a sensing system for measuring temperature, strain, or other properties of a metal structure. An optical system transmits light to and receives output signals from the sensor for analysis. With rotating structures, an optical fiber lead transmits light between the sensor and external surface of the structure along its rotational axis, allowing the lead to remain fixed with respect to the optical system as the structure rotates at high speeds.

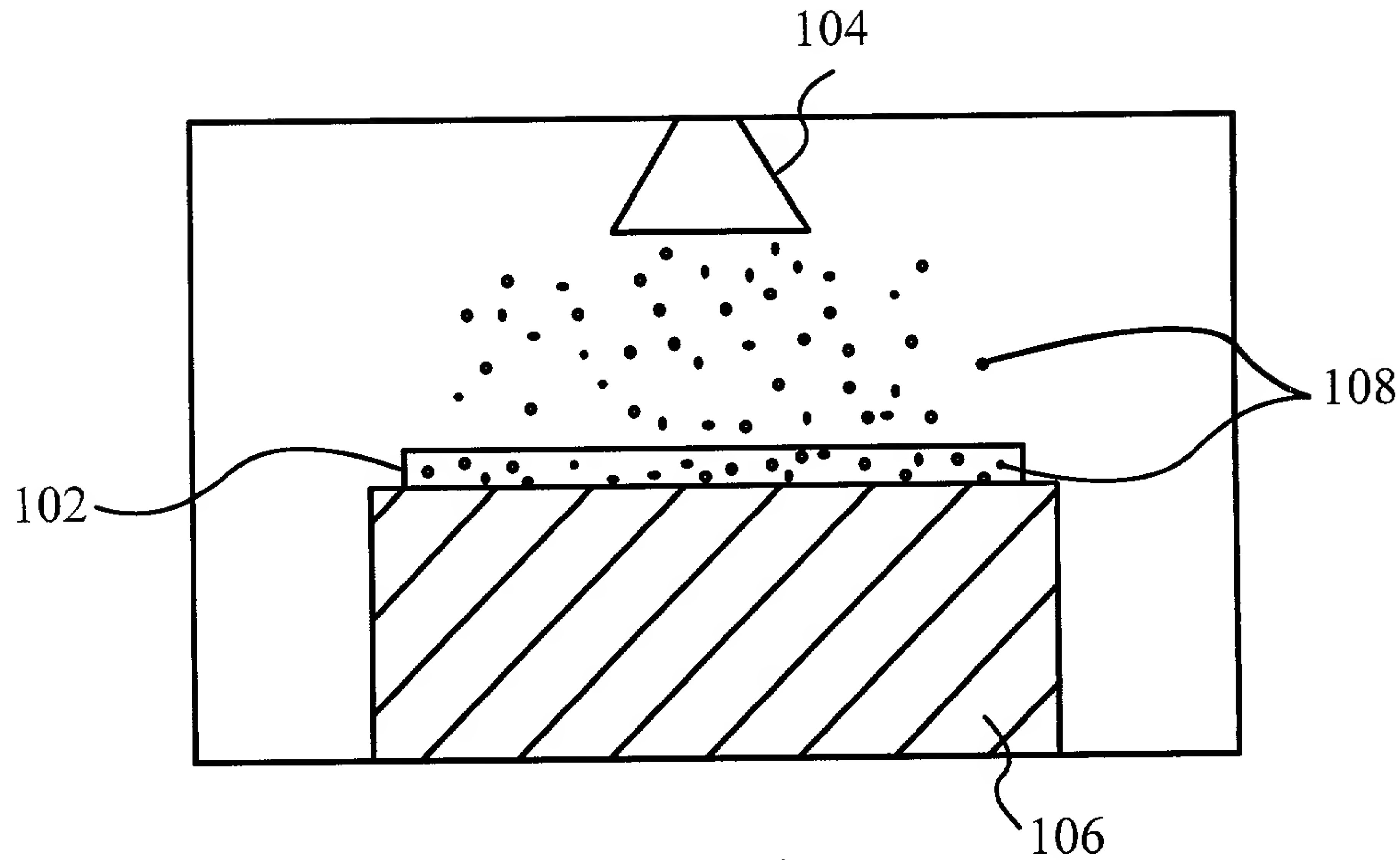

FIG. 1

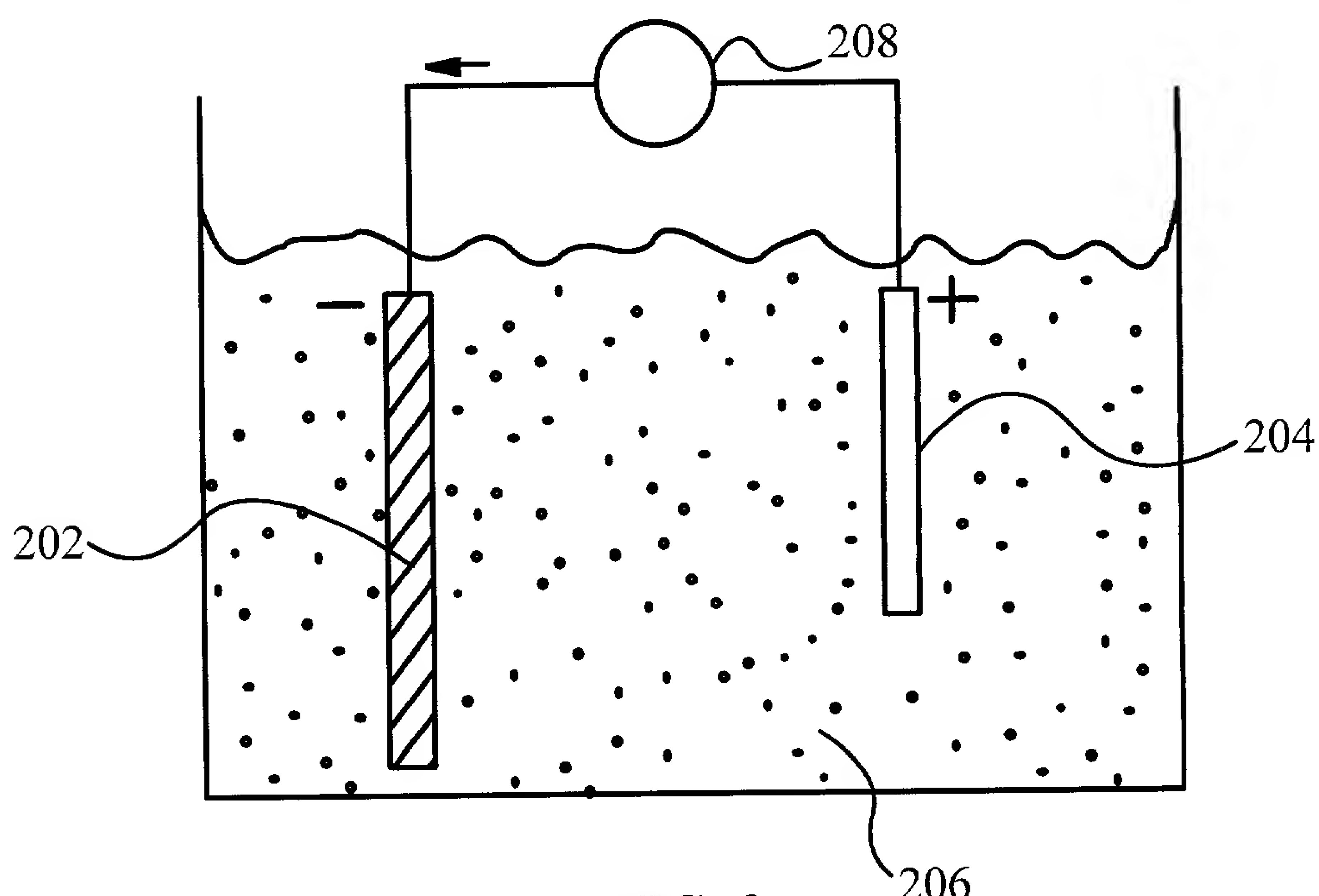

FIG. 2

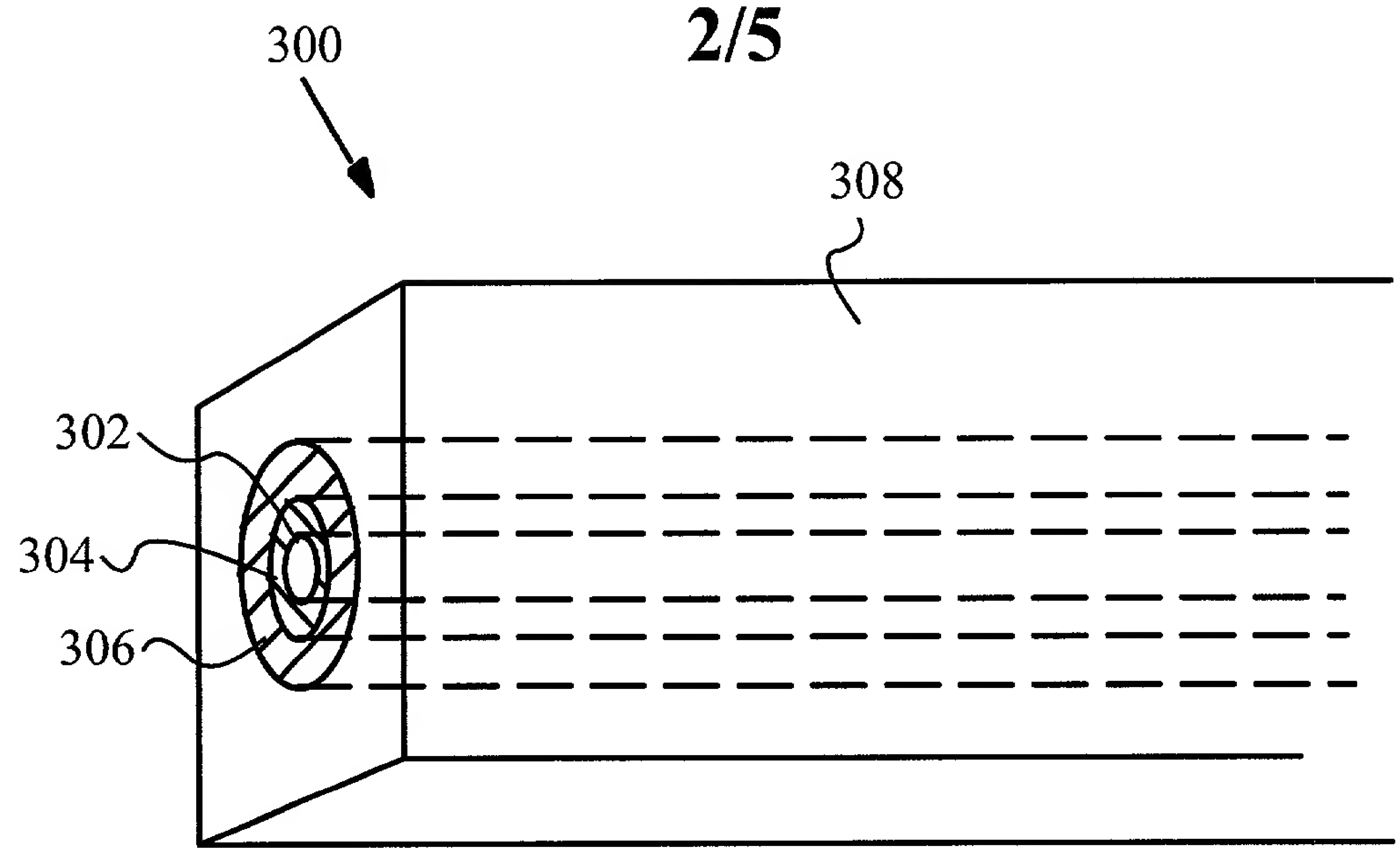

FIG. 3

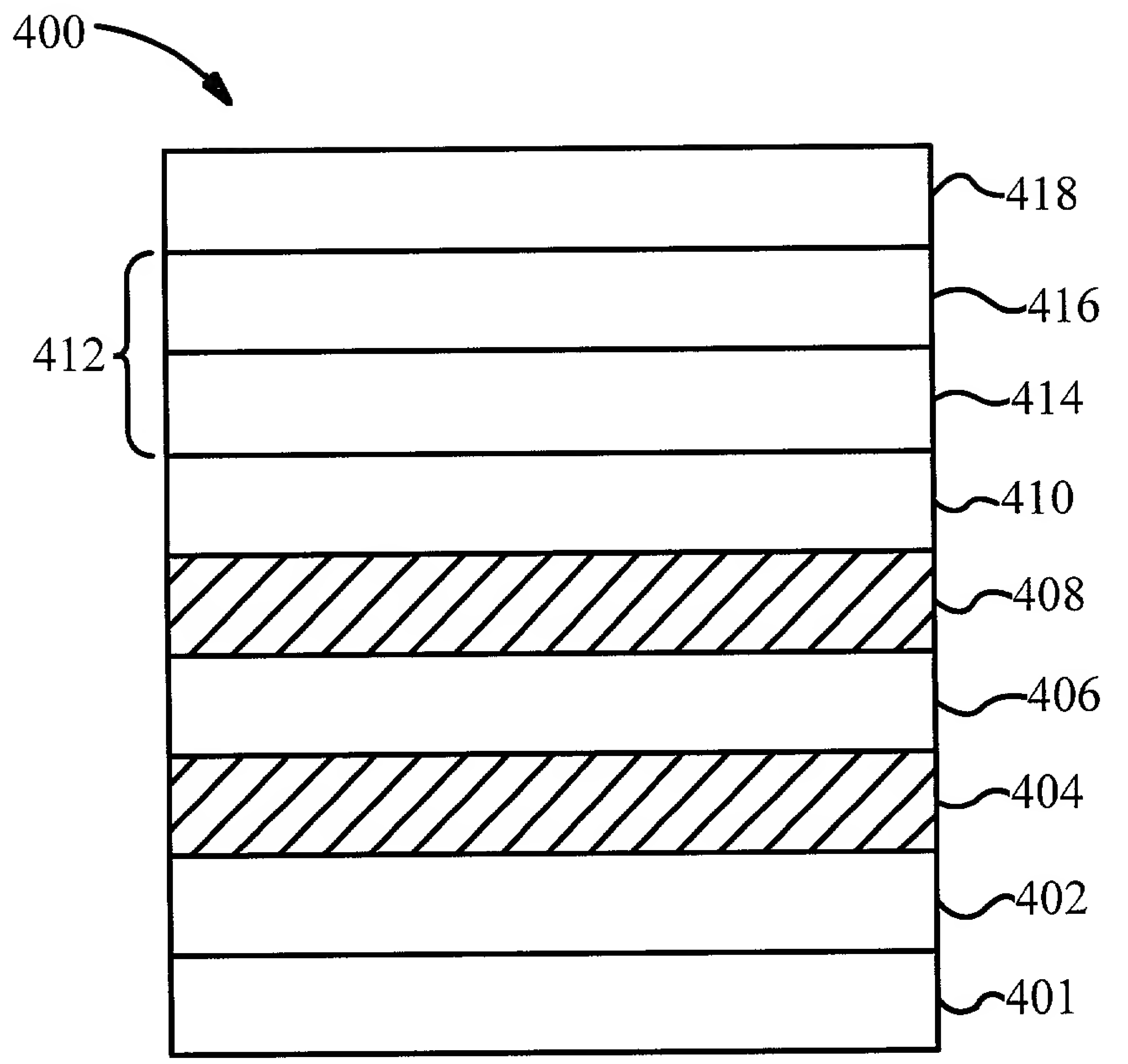
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FIG. 4A

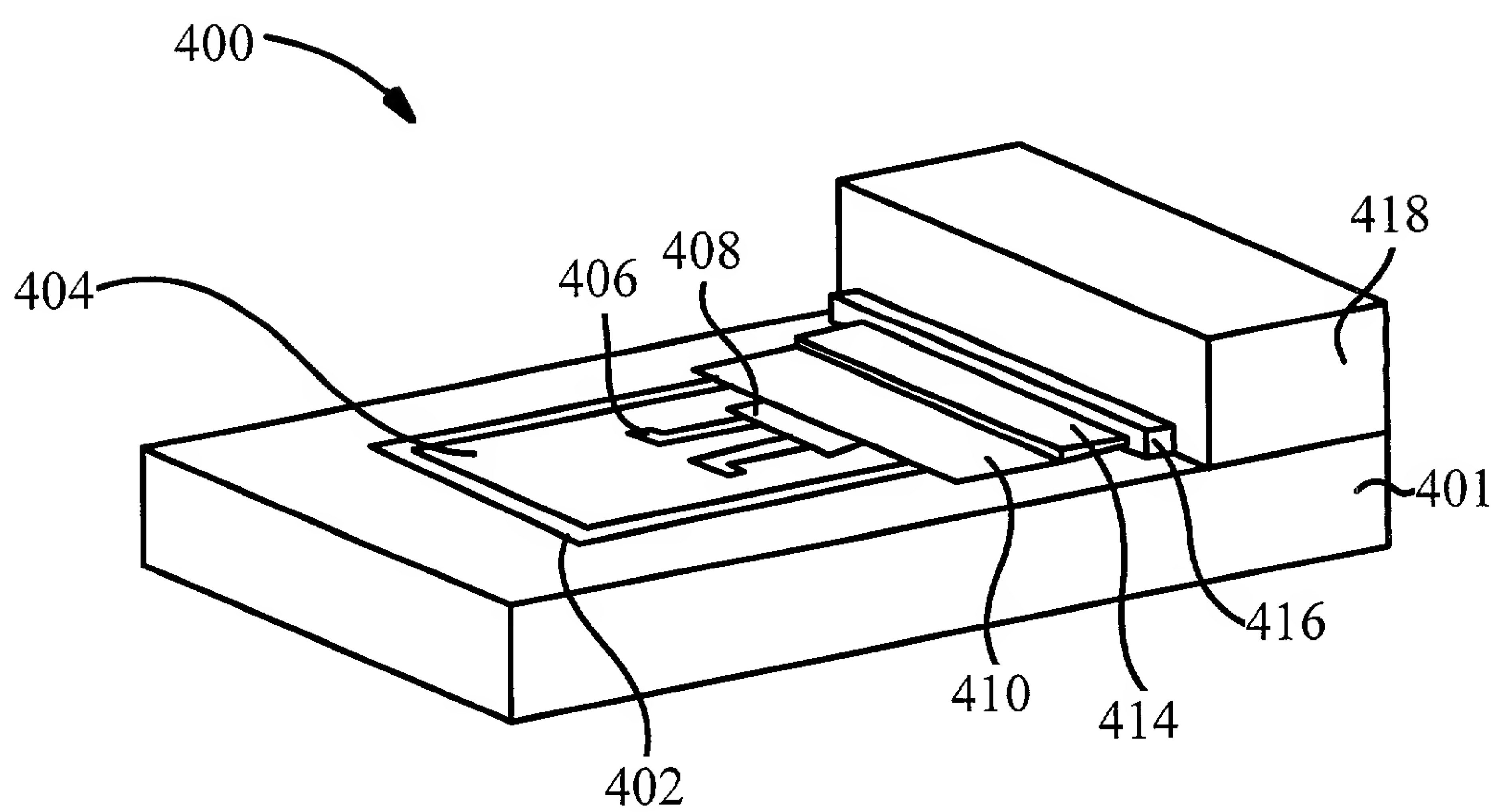
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FIG. 4B

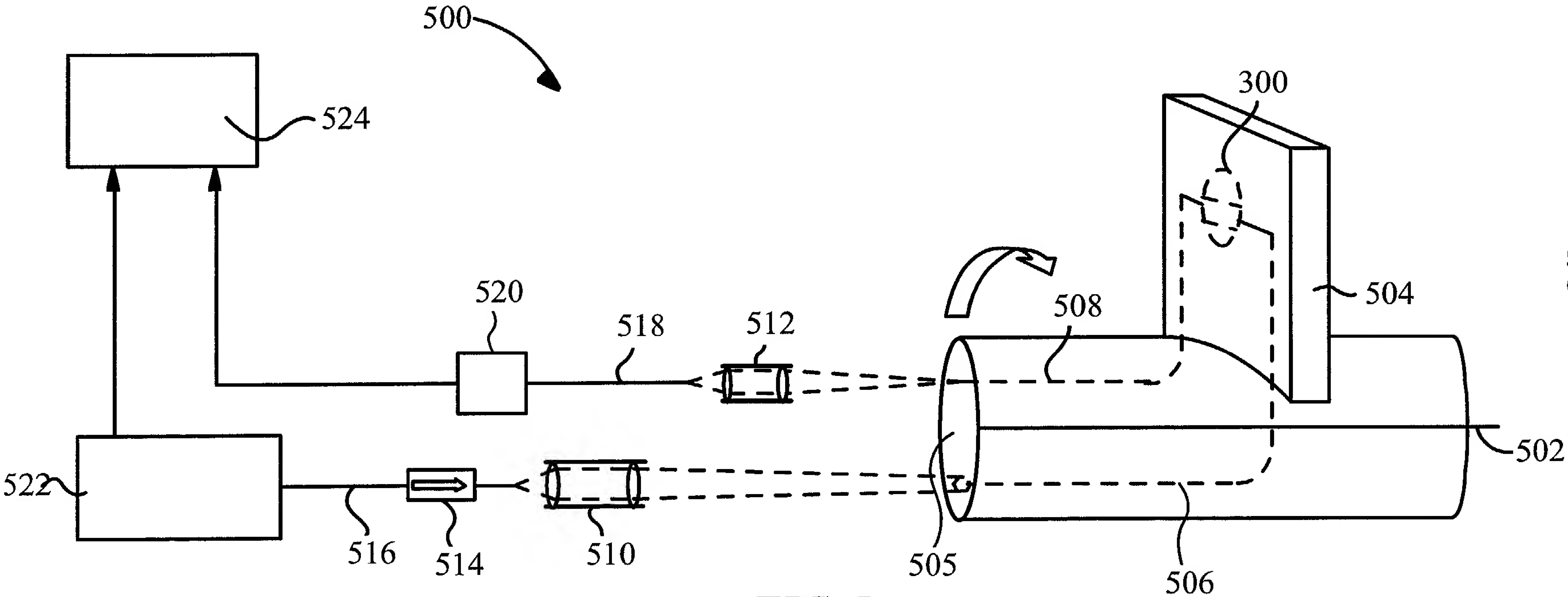
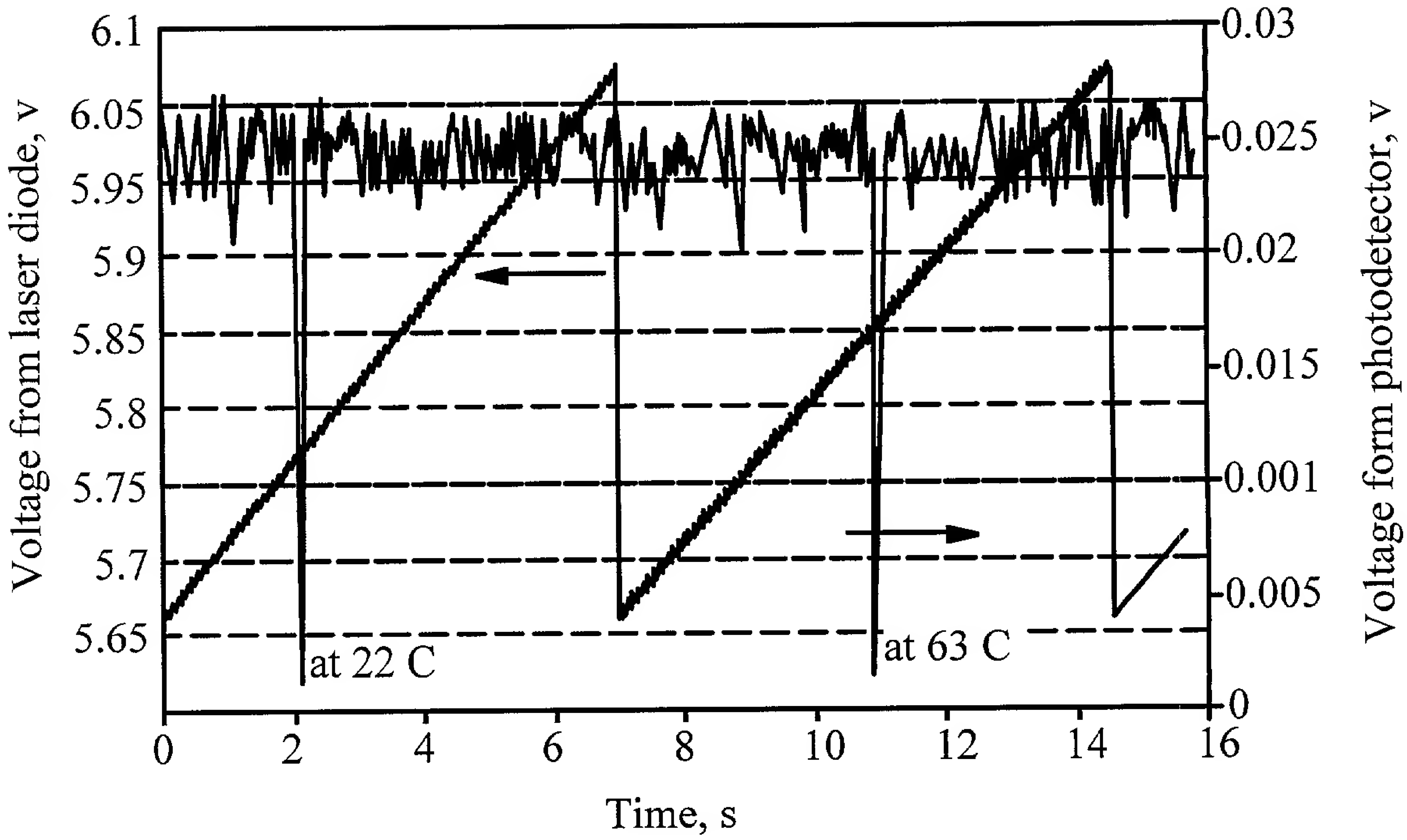


FIG. 5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6.05
5.95
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5.75
5.7
5.65
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0.02
0.015
0.001
0.005
0
Voltage form photodetector, v
at 22 C
at 63 C
0
2
4
6
8
10
12
14
16
Time, s

FIG. 6